THE FREQUENCY AND RADIO PROPERTIES OF BROAD ABSORPTION LINE QUASARS[1]

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ABSTRACT

A sample of 67 Broad Absorption Line quasars (BALQSOs) from the Large Bright Quasar Survey (LBQS) is used to estimate the observed and intrinsic fraction of BAL quasars in optically–selected samples at intermediate ($B_J \simeq 18.5$) magnitudes. The observed BALQSO fraction in the redshift range $1.5 \leq z \leq 3.0$ is 15 ± 3%. A well–determined, empirical, k–correction, to allow for the differences in the spectral energy distributions of non–BALQSOs and BALQSOs shortward of $\simeq 2100$Å in the restframe, is applied to the sample. The result is an estimate of the intrinsic fraction of BALQSOs, in the redshift range $1.5 \leq z \leq 3.0$, of 22 ± 4%. This value is twice that commonly cited for the occurrence of BALQSOs in optically–selected samples and the figure is in reasonable agreement with that from a preliminary analysis of the SDSS Early Data Release. The fraction of BALQSOs predicted to be present in an optical survey with flux limits equivalent to that of the FIRST Bright Quasar Survey (FBQS) is shown to be $\simeq 20$%. The BALQSO fractions derived from the FBQS and the LBQS suggest that optically–bright BALQSOs are half as likely as non-BALQSOs to be detectable as $S_{1.4\mathrm{GHz}} \gtrsim 1\,\mathrm{mJy}$ radio sources.

Subject headings: quasars: general—quasars: absorption lines—radio continuum: general—surveys

1. INTRODUCTION

Virtually every paper written in the last decade describing the phenomenology of the broad absorption line quasars (BALQSOs) contains the word “enigmatic”. Long thought to be a rare sub–class of quasars relegated to an esoteric sub–discipline of active galactic nuclei (AGN) studies, these objects have garnered new attention in recent years. It has become clear that the BALQSOs, while a minority class of quasars, are not rare. Furthermore, the evidence is strong that the absorbing gas responsible for the prominent, blueward–displaced absorption troughs from species covering a range of ionization from Mg II and Fe II through O VI may also be responsible for the “warm absorbers” seen at X-ray wavelengths (Brandt, Laor & Wills 2000). The BAL phenomenon is also almost certainly related to the ultraviolet absorption seen at low ejection velocities in a number of low luminosity AGN and to the “associated absorbers” seen in quasars at higher redshifts. A summary of the state of understanding mass outflows in AGN and the links between the BAL phenomena and other manifestations of outflows can be found in contributions included in Crenshaw, Kramer & George (2002).

While some progress has been made in understanding the link between the presence of broad absorption and the properties of quasar spectral energy distributions at other wavelengths, there

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is still no consensus concerning the origin and acceleration mechanism of the absorbing gas in BALQSOs. Indeed, the fundamental relation between BALQSOs and the quasar population as a whole remains open. Two broad classes of models have been proposed; what can be termed the "unified" and "evolutionary" schemes. In the former, whether a quasar is observed to have broad absorption troughs depends on our viewing angle to the quasar with respect to some preferred axis (Weymann et al. 1991; hereafter WMFH). In the evolutionary scheme, the broad absorption troughs are produced during some specific period in the evolution of the quasar, perhaps as it transforms itself from a fully–enshrouded object with a large infrared luminosity, through a BAL phase, into a normal quasar (e.g. Briggs, Turnshek & Wolfe 1984; Sanders 2002).

Independent of which general model holds (or if indeed neither obtains), the frequency of occurrence of the BAL phenomenon provides direct constraints on key physical parameters (e.g. Morris 1988). In the unified–scheme, the frequency bears on the covering factor of the BAL gas and, in the evolutionary–scheme, the frequency is related to the time spent in the BAL quasar phase relative to that spent as a normal quasar. Determining the frequency of the BAL phenomena as a function of redshift and strength of the absorption features would provide further constraints on the competing models. Notwithstanding the importance of establishing the frequency of the BAL phenomenon, there are very few such quantitative estimates in the literature. Few estimates that have been published contain both a detailed description of the calculation and are based on well–defined samples of quasars with numbers of objects sufficient to reduce the errors to an interesting level. For example, Foltz et al. (1992) provide few details of their calculation, Chartas (2000) employs a novel method but has very few objects and the recent determination by Tolea, Krolik & Tsvetanov (2002), based on the Sloan Digital Sky Survey (SDSS) Early Data Release (EDR), uses a large number of BALQSOs but the selection function, for quasars with different spectral energy distributions included in the EDR, is yet to be determined.

The difficulty in determining the frequency of BALQSOs is tied to their selection via the effect of the absorbing material along the line–of–sight on the spectral energy distribution (SED) of the quasars. Over extended ranges in frequency, such as the X–ray portion of the spectrum, BALQSOs may be under–represented in flux–limited samples due to the effects of the absorbing column. Within narrower frequency intervals, particularly in the rest–frame ultraviolet and optical portions of the SED, the extreme absorption equivalent widths of the BAL troughs can suppress the broad–band magnitudes well below those of a non–BALQSO of comparable luminosity and redshift to the extent that the BALQSO is excluded from a magnitude–limited sample. This effect is strongly dependent on both redshift, since most of the strong troughs occur in the rest–frame ultraviolet, and on ionization level, where some of the most extreme low–ionization BALQSOs show very strong depressions shortward of 2800Å.

It is still common practice to quote a figure of $\sim 10\%$ for the observed frequency of BALQSOs in the quasar population. The Large Bright Quasar Survey (Hewett, Foltz & Chaffee 1995, 2001) is cited as one of the main surveys from which the $\sim 10\%$ is derived (e.g. Stocke et al. 1992) and current observations of samples of BALQSOs using *Chandra* (Green et al. 2001; Gallagher et al. 2002) are based on samples drawn from the LBQS. Recently, Becker et al. (2000) used a figure of 10% for the BALQSO frequency in the LBQS, in conjunction with quasars from the FIRST Bright Quasar Survey (FBQS), to conclude that BALQSOs were in fact significantly more common in the FBQS than in optically–selected samples. This latter conclusion is at first sight inconsistent with the long–standing belief that BALQSOs are extremely rare amongst the population of quasars that are also luminous radio sources (Stocke et al. 1992).

Weymann (2002) has stressed the need to ensure that investigation of outflow phenomena in quasars does not become handicapped by placing great significance on precise definitions of classes of object. Rather, attention should be paid to trends that may provide insight into the underlying physics. Indeed, Weymann cites the potential limitations inherent in the original quantitative definition of the strength of BALs in spectra, the BALnicity Index (WMFH), given the subsequent recognition that outflows may also be responsible for many narrow absorption lines with much lower ejection velocities. However, clearly defined and reproducible schemes for the identification of BALQSO samples are a prerequisite if quantitative comparisons between the incidence of BALQSOs as a function of the properties of quasar SEDs are to be performed. For example, given the availability of spectra from the SDSS, Hall et al. (2002) have sensibly extended the original definition of the WMFH BALnicity Index to incorporate BAL troughs associated with low–ionization species, spectacular examples of which are included among the SDSS quasar sample.

Substantial progress in understanding the relation between BALQSOs and the quasar population as a whole has already been made given the availability of large samples of quasars from the SDSS (Hall et al. 2002; Tolea et al. 2002) and the FBQS (Becker et al. 2000). Further progress can be expected from these and other surveys, particularly those undertaken at near–infrared wavelengths, in the next few years. However, the lack of a well–determined fraction of BAL quasars from existing surveys, the continued use of samples from the Palomar–Green (Schmidt & Green 1983) and LBQS surveys for follow–up studies at other wavelengths (e.g. Green et al. 2001), combined with the seemingly contradictory conclusions regarding the radio–properties of BALQSOs argue for a reconsideration of the incidence of BALQSOs derived from apparently bright, optically–selected quasar surveys.

In §2 a sample of 67 candidate BALQSOs from the full LBQS sample is presented. A subset of 42 objects form a well–defined sample with redshifts $1.5 \leq z \leq 3.0$. Section 3 presents calculations of the observed fraction of BALQSOs in the LBQS. A two–dimensional BALQSO k–correction is developed to account for the under–representation of BALQSOs in the flux–limited LBQS and an estimate of the intrinsic fraction of BALQSOs is presented. Synthetic photometry applied to composite quasar spectra is used in §4 to calculate the fraction of optically–selected quasars predicted to be present in a sample of quasars with the same photometric selection criteria as the FBQS. Very different conclusions from those of Becker et al. (2000), regarding the probability a BALQSO is detected in the FIRST survey, are reached. The paper concludes with a discussion of the constraints on the demographics of BALQSOs from the LBQS, FBQS and SDSS surveys in §5.

2. THE BROAD ABSORPTION LINE QUASAR SAMPLE

The incidence of BALQSOs in the LBQS has been determined from a re–examination of the discovery spectra (Foltz et al. 1987, Foltz et al. 1989, Hewett et al. 1991, Chaffee et al. 1991, Morris et al. 1991, Hewett et al. 2001) of the current LBQS sample, comprising the 1055 objects from Hewett et al. (1995) and the 12 additional objects listed in Table 1 of Hewett et al. (2001). In practice, the objects of interest are predominantly those flagged in the discovery papers as "b", "b?" or "b??", corresponding to definite, probable or possible BALQSOs. A significant number of these objects possess additional spectra of higher quality from the investigations of WMFH and Korista et al. (1993).

Classification of a quasar as a BALQSO was based on the BALnicity index of WMFH applied to the C IV λ1549 emission line. The BALnicity index attempts to characterize the absorption by measuring essentially the equivalent width of the absorption feature, expressed in $\mathrm{km\,s^{-1}}$, with the additional constraints that the absorption must be contiguous over $2000\,\mathrm{km\,s^{-1}}$ and must lie more than $3000\,\mathrm{km\,s^{-1}}$ blueward of the broad emission line redshift. The C IV λ1549 emission line and any associated absorption lie within the atmospheric window only for redshifts $z \gtrsim 1.3$. Furthermore, to determine a BALnicity for an object it is necessary to be able to define a reliable continuum level. For quasars with redshifts $z \sim 1.4$ the proximity of C IV λ1549 absorption to the atmospheric edge, combined with the only moderate quality of some of the spectra, means that a reliable continuum level could not always be defined, precluding the measurement of the BALnicity for a small number of objects. There are six such quasars included in Table 1, five of which are assigned to the "possible" BAL category. Only one candidate BALQSO, B2210-1751, among the sub–sample of 42 candidate BALQSOs used in subsequent sections is without a measured BALnicity Index. A modest value of BALnicity= $1000\,\mathrm{km\,s^{-1}}$ has been adopted for B2210-1751 for the purposes of the calculations in §3 onwards.

For quasars with redshifts $z < 1.2$, identification of (low–ionization) BALQSOs, was based on the presence of absorption associated with the Mg II λ2798 emission line. The WMFH procedure for measuring BALnicity was developed for application to C IV λ1549 which is not available in the spectra of the low–redshift quasars. Application of a modified WMFH BALnicity procedure to the Mg II λ2798 is possible (e.g. Hall et al. 2002) but the continuum placement is particularly problematic in this spectral region where Fe II emission can vary dramatically from object to object. Given a significant number of spectra with both C IV λ1549 and Mg II λ2798 BAL troughs present, an assessment of the relation between BALnicity defined using both lines would be possible. However, given the small number of low–ionization BALs identified from their Mg II λ2798 line properties, none of which possess spectra including C IV λ1549, we have chosen not to derive BALnicity indices for these quasars.

For the majority of candidate BALQSOs, visual inspection coupled, where appropriate, with the application of the BALnicity determination, produces an unambiguous classification of an object as a BAL. Exceptions, as discussed above, include some quasars with $z \sim 1.2$. Similarly, given the complex nature of quasar SEDs in the region of Mg II it is not always clear whether apparent absorption features do indicate the presence of broad absorption as opposed to local minima in the Fe II emission complexes. As a consequence we have assigned a probability ($P(\mathrm{BAL}) =$ 1.0, 0.7, 0.3), essentially equivalent to "definite", "probable" or "possible" BAL categories, to each quasar identified as a potential BAL. Table 1 summarises the properties of the 67 candidate BALQSOs identified in the LBQS. Column 1 gives the LBQS name, derived from the B1950.0 coordinates; columns 2–3, the J2000.0 right ascension and declination; column 4, redshift; column 5, B_J magnitude; column 6; probability quasar is a BAL; column 7, BALnicity index, where available; column 8, classification as a low– or high–ionization BAL (L or H) for those objects where spectral coverage of the Mg II λ2798 line is available; column 9, reference to source of the BALnicity measures. The BALnicity measures in column 7 have been taken from WMFH and Korista et al. (1993) with the average value adopted for objects appearing in both papers. The source of the BALnicity measure is denoted in column 9 as "K" for Korista et al. and "W" for WMFH. Additional BALnicity measures come from application of the WMFH BALnicity estimation procedure to the LBQS spectra. The probabilities adopted by WMFH for the "L" classifications of two quasars are included in brackets in column 8. Comparison of the BALnicity indices for the objects in common between WMFH and Korista et al. (1993) indicate that the uncertainty in the BALnicity values is $\simeq 30\%$. However, larger errors can result due to the constraint in the definition of BALnicity that the absorption be contiguous over $2000\,\mathrm{km\,s^{-1}}$ or more. Uncertainty in the placement of the continuum in objects with complex absorption troughs can lead to discrepant estimates due to the resetting of the integral when the flux rises above 90% of the continuum level (see WFHM for details). Extreme examples of differences in the measured BALnicity values are B1231+1320, with BALnicity$= 5772\,\mathrm{km\,s^{-1}}$ (WMFH) and BALnicity$= 1174\,\mathrm{km\,s^{-1}}$ (Korista et al.), and B1138–0126 for which we derive BALnicity$= 3523\,\mathrm{km\,s^{-1}}$, whereas Brotherton et al. (2002) obtain BALnicity$= 900 \pm 300\,\mathrm{km\,s^{-1}}$.

3. THE FRACTION OF BROAD ABSORPTION LINE QUASARS IN THE LBQS

3.1. The Observed Fraction of Broad Absorption Line Quasars

Straightforward estimates of the observed fraction of BALQSOs in the LBQS can be derived using the sample presented in Table 1 together with the statistics of the full LBQS. The predicted number of LBQS quasars within a specified redshift and magnitude range can be calculated by summing the factors

$$N_{quasar} = \sum_{n=1}^{1067} \frac{1}{z_{comp}} * \frac{1}{m_{comp}} * P \qquad (1)$$

for all quasars within specified redshift and apparent magnitude limits. The redshift completeness factors z_{comp} for each quasar are given in Table 7 of Hewett et al. (2001) and the fraction of the LBQS survey area extending faint enough to include a quasar of a specified magnitude, m_{comp}, is calculated using the magnitude limits and associated areas of sky given in Table 2 of Hewett et al. (1995). To calculate the total number of quasars within a specified redshift and magnitude range the probabilities, P, are set to unity. The associated number of BALQSOs is calculated using the probabilities given for each quasar in column 6 of Table 1. Table 2 summarizes the statistics of the fraction of BALQSOs for different redshift and magnitude ranges. Section A of the table relates to estimates of the fraction of BALQSOs calculated from equation (1). Section B of the table provides information concerning the intrinsic fraction of BALQSOs, calculated using equation (1) with the addition of the multiplicative weighting term defined in equation (3) (see §3.2). Column 1 specifies the redshift range; column 2 specifies the magnitude range; column 3 lists the total number of quasars satisfying the redshift and magnitude limits; column 4 gives the number of non–BALQSOs calculated using equation (1); column 5 specifies the number of BALQSOs used in the calculations; column 6 gives the number of BALQSOs calculated using equation (1) (Section A), or, using equation (1) with the addition of the weighting term defined in equation (3) (Section B); column 7 gives the fraction of BALQSOs, calculated from columns 4 and 6.

The observed fraction of BALQSOs exhibiting high–ionization troughs has been calculated for redshift ranges where C IV $\lambda1549$ is present in the spectra, i.e. $z \geq 1.3$. To be absolutely confident that the presence of the atmospheric cutoff does not affect the identification of BALs a lower limit of $z = 1.5$ has also been employed. The statistics employing the $z = 1.5$ redshift limit are also directly comparable to a sample of BALQSOs taken from the FIRST survey (Becker et al. 2000) – see §4. An upper redshift limit of $z = 3.0$ has been adopted due to the increasingly small fraction of the B_J passband occupied by the quasar SED longward of Lyman α $\lambda1216$ and the corresponding increased uncertainty in the BAL k–correction due to the presence of N V $\lambda1240$ and Lyman α $\lambda1216$ absorption troughs. In fact there are only 9 quasars with $z > 3.0$ in the LBQS sample, none of which is a BAL, and their inclusion would make no significant difference to the statistics. The straightforward calculation of the observed frequency yields 0.14 ± 0.03 and 0.15 ± 0.03% for lower redshift bounds of 1.3 and 1.5, respectively (Table 2).

To identify a low–ionization BALQSO from the LBQS discovery spectra it is necessary that Mg II $\lambda2798$ is present longward of the atmospheric cutoff and shortward of $\sim$ 5600Å, where the signal–to–noise ratio (S/N) of the discovery spectra has declined significantly from the target of S/N $\simeq 10$ at 4500Å. The redshift range over which the probability of identification of low–ionization BALQSOs in the LBQS is relatively constant is thus $0.3 \leq z \leq 1.0$. There are 379 LBQS quasars in this redshift range with magnitudes $B_J \geq 16.5$. Only 5 quasars are candidate BALQSOs (2 definite; 2 probable; 1 possible), leading to an estimate of the observed frequency of low–ionization BALQSOs of $\simeq 1$% with a large associated error.

Given the relatively small number of BALQSOs in the sample, it is important to verify that a few objects with large weighting factors are not contributing disproportionately to the statistics. In fact, the redshift completeness factors are small and independent of redshift within the range $1.3 \leq z \leq 3.0$ and vary only by ~ 10% for $0.3 \leq z \leq 1.0$. Thus, the deductions concerning the observed frequency of BALQSOs are virtually independent of any reasonable change to the redshift completeness factors employed. The magnitude correction factors are defined accurately by the fraction of the LBQS that extends to a given magnitude limit. As the entire LBQS extends to $B_J = 18.41$ the area completeness factors are unity brighter than this limit and the completeness correction remains less than a factor two for all quasars with $B_J \leq 18.64$. However, the LBQS extends fainter than $B_J = 18.77$ in only a few of the 18 fields making up the survey. The completeness correction is $\simeq 10$ for $18.77 < B_J \leq 18.80$ and reaches $\simeq 20$ for $18.80 < B_J \leq 18.85$ where only a single field reaches $B_J = 18.85$. Sixty–five of the 67 candidate BALQSOs in Table 1 possess magnitude completeness factors ≤ 2.6 but two objects, 1231+1320 and 1240+1607, both of which have magnitudes $B_J = 18.84$, just brighter than the magnitude limit of the deepest LBQS field, have completeness factors of 21.6! Nonetheless, splitting the LBQS into a bright and faint sample, with the boundary set at $B_J = 18.41$, demonstrates that the inferred fraction of BALQSOs is not unduly sensitive to the details of the magnitude range employed (see Table 2).

3.2. The Intrinsic Fraction of Broad Absorption Line Quasars

To estimate the intrinsic fraction of BALQSOs, it is necessary to account for the effect of the BAL troughs on the definition of the flux–limited LBQS sample; effectively the BALQSO k–correction. Specifically, the broad–band magnitudes of BALQSOs appear fainter than equivalent non–BALQSOs for redshifts where the BAL troughs fall within the passband defining the broad–band magnitude. For objects with high values of BALnicity, the size of the effect can be significant. Quantitative corrections for this effect have been applied when comparing the properties of BALQSO and non–BALQSOs (e.g., Stocke et al. 1992). There is also some evidence that the shapes of the restframe ultraviolet to optical spectral energy distribution of BALQSOs and non–BALQSOs differ, although the effect may be significant only for the subset of low–ionization BALQSOs (Sprayberry & Foltz (1992), Hall et al. (2002), Yamamoto & Vansevičius (1999)).

The B_J passband that defines the LBQS flux–limited sample has an effective wavelength of $\simeq$ 4600Å and extends from 3850Å to 5300Å. The BAL trough associated with C IV λ1549 enters the passband at $z \simeq 1.5$ and one or more BAL troughs associated with C IV λ1549, Si IV λ1400, N V λ1240 and Lyman α λ1216 fall within the B_J passband for the entire redshift range, $1.5 \leq z \leq 3.0$, used to estimate the frequency of BAL quasars in §2.2. Thus, there is a potentially significant BALQSO k–correction that affects the fraction of BALQSOs included in the LBQS.

WMFH presented 54 high–quality spectra of BALQSO and non–BALQSOs from the LBQS, augmented by 17 spectra of BALQSOs from other surveys. The spectra have good relative spectrophotometry over a wide wavelength range and so can be employed to quantify the relative fluxes that would be observed at specified continuum wavelengths or through particular broad–band filters. The WMFH spectra can be employed individually or combined to produce composite spectra. Two–dimensional BAL k–corrections, as a function of redshift and BALnicity, were constructed using composite BALQSO spectra, as specified in Table 3, compared to the composite of the WMFH non–BALQSO LBQS quasars. The selection of the BALnicity index boundaries was made so that approximately equal numbers of objects contribute to each composite. For the most extreme objects, BALnicity$>$ 6000 km s^{-1}, it was also possible to generate separate composite spectra using just the high–ionization and low–ionization objects. The new composite spectra were generated using the same procedures as described in WMFH. Information relating to the composite spectra is summarized in Table 3. Column 1 is a name, with "H" and "L" denoting composites constructed from just high– and low–ionization BALQSO spectra respectively; column 2 gives the number of spectra contributing to each composite; column 3 specifies the range of BALnicity values of the spectra used to generate the composite; column 4 lists the BALnicity of the composite spectrum.

The non–BALQSO and BALQSO composite spectra are extremely similar at wavelengths $>$ 1600Å. Normalising the spectra using the average flux over the interval 1600 − 2600Å produces B_J magnitudes all within 0.01 mag of each other at redshift $z = 1.3$. The BAL k–corrections are calculated from the difference in the B_J magnitudes of each BALQSO composite compared to the non–BALQSO composite at a specified redshift. The k–correction for a particular BALnicity was derived by interpolating between the loci defined by the non–BALQSO and the BALQSO composite spectra. Linear extrapolation was used for quasars with BALnicity exceeding the BALnicity of the strongest BALQSO composite used. The two–dimensional k–corrections for the composite spectra are plotted in Figure 1. Notwithstanding the substantial range in the appearance of individual BALQSOs, the k–correction calculated from these composite spectra varies smoothly and is extremely well–behaved, both as a function of redshift and BALnicity. It might be supposed that the use of composite spectra made up of only high–ionization or low–ionization BALQSOs would result in significantly different k–corrections for a specified BALnicity. Certainly, the larger the BALnicity index, the greater the probability that an object shows evidence for low–ionization BALs. The separate high– and low–ionization composite spectra for the objects with BALnicity$>$ 6000 km s^{-1} do have very different mean

BALnicity values, $7990\,\mathrm{km\,s^{-1}}$ and $9689\,\mathrm{km\,s^{-1}}$ respectively, but the results described in this section are completely insensitive to which of the three BALnicity$>6000\,\mathrm{km\,s^{-1}}$ composites (All, High, Low) is used to generate the k–corrections. In other words, although the loci used to define the k–corrections differ (Figure 1), the interpolated values for a specified BALnicity and redshift are very similar for objects with BALnicity$\lesssim 10000\,\mathrm{km\,s^{-1}}$. The results of the application of the k–corrections calculated according to this prescription are also not sensitive to the details of the interpolation.

The reference non–BALQSO spectrum used is the WMFH non–BALQSO composite spectrum, based on 29 quasars, which is slightly redder than the composite spectra derived from larger fractions of the LBQS employed in Hewett et al. (2001). However, the much closer match in redshift to the sample of BALQSOs under consideration make the WMFH–composite the reference of choice. Use of the composite from Hewett et al. (2001) produces small increases in the the inferred intrinsic fractions of BALQSOs compared to the values given in Table 2.

Making the assumption that the fraction of BALQSOs does not change significantly close to the LBQS flux limit, an estimate of the true fraction of BALQSOs that would be included in the survey, correcting for the depressed apparent magnitudes due to the presence of the BAL troughs, can be made. For the 42 LBQS BALQSOs, an additional, multiplicative, weighting factor

$$W_{c1} = \frac{N_{quasar}(\leq 18.85)}{N_{quasar}(\leq 18.85 - \Delta m_k)} \qquad (2)$$

is included in equation (1). $N_{quasar}(\leq 18.85)$ is the number of quasars, within some specified redshift range, to the original LBQS flux limits, Δm_k is the BAL k–correction in magnitudes for the quasar and $N_{quasar}(\leq 18.85 - \Delta m_k)$ is the number of quasars, within the same specified redshift range, to the revised (brighter) LBQS flux limits for the BAL quasar. The result of this procedure is an estimated BALQSO fraction of $19 \pm 3\%$. To ensure that the calculation is not sensitive to the exact values of the BAL k–corrections, the calculation was repeated using individual BAL k–corrections for 23 of the BALQSOs derived directly from the WMFH spectra. Essentially identical results were obtained.

A somewhat more sophisticated calculation can be performed to allow for the strong dependence of the BALQSO k–correction on redshift. The importance of allowing for a redshift–dependence can be gauged by noting that all 5 BALQSOs with BALnicity$>6000\,\mathrm{km\,s^{-1}}$ have redshifts $1.5 < z < 1.9$, where the effect of the BAL–troughs on the broad–band B_J magnitudes is smallest.

Assuming that the fraction of BALQSOs is constant over the redshift interval $1.5 \leq z \leq 3.0$, the weighting factor included in equation (1) becomes

$$W_{c2} = \frac{N_{quasar}(\leq 18.85)}{N_{quasar}(\leq 18.85 - \Delta m_k(z))} \qquad (3)$$

where the quantities are as defined for equation (2), except that $\Delta m_k(z)$ is now a function of redshift. Figure 2 illustrates the nature of the calculation graphically. The use of the two–dimensional k–correction is effectively the best that can be achieved given the information available. Applying the weighting factors calculated using equation (3), the estimated intrinsic BALQSO fraction over the full LBQS magnitude range with $1.5 \leq z \leq 3.0$ rises to $22 \pm 4\%$, with one–quarter of the population of BALQSOs possessing BALnicity$>4000\,\mathrm{km\,s^{-1}}$. The calculated intrinsic fractions are presented for three magnitude ranges in Table 2.

The resulting estimate of the intrinsic fraction of BALQSOs is still in practice a lower limit because it has been assumed that the sample of 42 LBQS BALQSOs is a fair representation of the parent BALQSO population. This is manifestly not the case because the direct relation between BALnicity and the size of the BAL k–correction means that quasars with larger BALnicity values are increasingly under–represented among the sample of 42 LBQS BALQSOs. The procedure described above corrects for the systematic under–representation, providing that quasars of a given BALnicity appear in the sample. For the most extreme objects, those with $10000 <$ BALnicity $<20000\,\mathrm{km\,s^{-1}}$, this is not the case. The extreme BALQSO B1232+1325, with redshift $z = 2.364$ and BALnicity$=12792\,\mathrm{km\,s^{-1}}$, provides a direct example. B1232+1325 lies within the LBQS survey area and possesses an objective–prism spectrum that would make it one of the most readily detectable quasars in the entire survey. However, the broad–band magnitude, $B_J = 18.77$, means the quasar falls just below the LBQS flux–limit in the field. The BAL k–correction, determined directly from the WMFH–spectrum as described above, is 1.01 mag, giving a corrected magnitude of $B_J = 17.76$. Assuming the fraction of BALQSOs does not vary over the redshift interval $1.5 \leq z \leq 3.0$, the effective depth of the LBQS for a quasar with BALnicity$= 12792\,\mathrm{km\,s^{-1}}$ is reduced by a factor of 4.5 compared to a non–BALQSO. For BALnicity$= 15000\,\mathrm{km\,s^{-1}}$ the effective depth of the survey is reduced by a factor of $\simeq 7$, equivalent to only $\simeq 55$ quasars, and thus the LBQS sample has essentially no sensitivity to BALQSOs with BALnicity$\geq 15000\,\mathrm{km\,s^{-1}}$.

The conclusion that, using the well–defined BALnicity criterion of WMFH, the proportion of BALQSOs in the redshift range $1.5 < z < 3.0$, with corrected magnitudes $16.5 < B_J < 18.75$, is at least one in five ($22 \pm 4\%$) is one of the main results of this work. The proportion is essentially twice the figure generally quoted.

4. FREQUENCY OF BROAD ABSORPTION LINE QUASARS IN THE FBQS

The application of the k–correction described in §3.2 leads to a predicted fraction of BALQSOs of $22 \pm 4\%$ for samples of quasars with redshifts $1.5 \leq z \leq 3.0$ selected according to a continuum flux–limit at restframe wavelengths $\simeq 2100$Å. Assuming that the intrinsic SEDs of non–BALQSO and BALQSOs are similar over larger wavelength ranges, then the corrected fraction of BALQSOs in samples defined at other wavelengths is predicted to be the same. While there is clear evidence at X–ray wavelengths for the presence of additional absorbing material (Green et al. 1995, 2001), more observations of larger samples are required before a meaningful comparison of the fraction of BALQSOs determined at restframe X–ray and ultraviolet wavelengths is possible. At the opposite wavelength extreme, the lack of BALQSOs detected as strong radio–sources led to suggestions that the SEDs of non–BALQSO and BALQSOs at radio wavelengths were intrinsically different (Stocke et al. 1992). The existence of this potentially important difference in the SEDs of the two classes of quasars has been challenged by Becker et al. (2001) who discuss the incidence of BALQSOs in the FBQS survey (White et al. 2000), concluding that "The frequency of BALQSOs in the FBQS is significantly greater, perhaps by as much as a factor of 2, than that inferred from optically–selected samples."

The conclusion of Becker et al. relies on the adoption of a BALQSO fraction for optically–selected samples of only 10%, combined with an extended definition of "BAL" quasars in the FBQS that differs from that applied in the optical samples. Employing a consistent definition for the identification of BALQSOs in both samples and incorporating the revised estimate for the incidence of BALQSOs from §3.2 leads to a very different conclusion.

Of the 29 quasars presented in Becker et al., 17 have redshifts $1.5 \leq z \leq 3.0$ and magnitudes $16.0 \leq E \leq 17.8$. Four of these objects possess a BALnicity index of zero and should not be included when comparing to samples which, by definition, require BALnicity> 0. Therefore, Becker et al.'s sample contains 13 objects with positive BALnicity that could have been identified from the LBQS discovery spectra. There are 142 quasars, of all types, in the FBQS within the same redshift and magnitude range, leading to an estimate of the fraction of BALQSOs of $9 \pm 3\%$. In contrast to the B_J passband, that defines the LBQS selection, the Palomar E passband ($\lambda_{eff} \simeq 6400$Å, $\Delta\lambda \simeq 400$Å) samples the same restframe wavelengths ($1600 - 2600$Å) at redshifts $z \sim 2$ used to match the SEDs of non–BALQSO and BALQSO SEDs in §3. The E passband is also unaffected by the presence of both high–ionization and low–ionization BAL troughs for redshifts $1.5 \leq z \leq 3.0$, so the BAL k–correction is essentially zero and the observed fraction is equivalent to the intrinsic fraction of BALQSOs.

As a consistency check, it is possible to construct directly a Palomar E–band–limited quasar sample, an optically–selected equivalent to the FBQS, using the LBQS sample. The procedure is described in detail in Hewett et al. (2001) but an outline is included here. Broadband colours were calculated using the Palomar O and E sensitivity curves of Minkowski & Abell (1963) and our own determination of the B_J sensitivity. The filter plus emulsion sensitivity curves were combined with one reflection off aluminum and atmospheric absorption and extinction appropriate for observations made at an airmass of 1.3 for a relatively low–altitude site such as Siding Spring or Mount Palomar. Synthetic photometry was performed using the `synphot` package in the Space Telescope Science Data Analysis System.

The measured $B_J - E$ and $O - E$ colours for the WMFH non–BALQSO composite spectrum, as a function of redshift, can be used to estimate an E–magnitude and $O - E$ colour for each non-BALQSO in the LBQS. For the BALQSOs a directly analogous procedure to that employed to produce the two–dimensional k–correction in §3.2 is used. The $B_J - E$ and $O - E$ colours for the BALQSO composite spectra are calculated as a function of redshift. The resulting loci in the $B_J - E$ and $O - E$ *versus* z planes are then used to provide an E–magnitude and $O - E$ colour for each of the 42 BALQSOs, with given BALnicity and z, via interpolation. The pseudo–E–limited sample is then derived by requiring the quasars to have magnitudes in the range $16.0 \leq E \leq 17.8$ and $O - E \leq 2.0$, i.e., the magnitude selection limits of the FBQS, excluding the very brightest objects. A limit of $E < 16.0$ is used because the majority of quasars brighter than this limit would not satisfy the $B_J \leq 16.5$ limit of the LBQS. The result of the procedure applied to the 375 LBQS quasars is a sample of 225 quasars, of which 45 are BALQSOs, giving a predicted BALQSO fraction of $20 \pm 3\%$. The result is insensitive to which of the BALnicity$> 6000\,\mathrm{km\,s^{-1}}$ composite spectra are used because whether the few objects with large BALnicity fall within the E flux limits does not change as different composite spectra are used to calculate the $B_J - E$ colours. The proportion of BALQSOs predicted for an optically-selected sample equivalent to the FBQS derived using this direct procedure is expected to be very similar to the 22% derived in §3.2 because the E–band flux limit is equivalent to the $1600 - 2600$Å restframe region used to normalise the SEDs of the non–BALQSO and BALQSO spectra.

The results of the comparison do not apply to BALQSOs with extreme BALnicities, BALnicity$\gtrsim 15000\,\mathrm{km\,s^{-1}}$, because of the lack of sensitivity of the LBQS to such BALQSOs. The E–band flux limit that defines the FBQS is not so affected but the requirement that objects have $O - E \leq 2.0$ will result in the exclusion of BALQSOs with BALnicity$\gtrsim 15000\,\mathrm{km\,s^{-1}}$ at redshifts $\gtrsim 2.6$. However, the results of a like for like comparison between the fraction of BAL quasars in the LBQS and the FBQS is that the BALQSOs are only half as common in the FBQS. While larger samples of objects, from SDSS, will improve the accuracy of this figure, the result is statistically significant and produces a very different interpretation to that of Becker et al.

5. DISCUSSION

5.1. The Fraction of BALQSOs in the LBQS

A primary conclusion of this paper is that over the redshift range $1.5 \leq z \leq 3.0$ the observed fraction of BALQSOs in the LBQS is $15 \pm 3\%$. This result involves no correction for differences in the SEDs between non–BALQSO and BALQSOs. Application of a well–determined BAL k–correction to allow for the differences in the SED shortward of ~ 2000Å results in an estimate of the intrinsic fraction of BALQSOs of $22 \pm 4\%$. These results supersede those given in Foltz et al. (1990) which were based on a preliminary version of the LBQS catalogue. The higher fraction of BALQSOs, both observed and inferred, in a bright optically–selected sample has significant implications for the interpretation of recent results concerning the fraction of BALQSOs in the FBQS (Becker et al. 2001) and the SDSS EDR (Tolea et al. 2002) since both papers use an estimate of $\simeq 10\%$ for the fraction of BALQSOs in the LBQS.

5.2. Redshift Dependence of the BALQSO Fraction

There are insufficient objects in the LBQS sample to place useful constraints on any redshift dependence of the BALQSO fraction. However, the distribution of objects with redshift is consistent with no $z-$dependence. This contrasts with the results of Tolea et al., who present evidence in their Figure 1 for a significant variation in the BALQSO fraction with redshift. Tolea et al. note specifically that selection effects in the construction of the SDSS EDR sample may be important. It is noteworthy that the systematic rise in the BAL fraction, from $\sim 10\%$ at $z = 2.0$ to a peak of $\sim 30\%$ at $z = 2.7$, followed by a decline to $\sim$ 15% at $z = 3.2$, coincides with the strong change in the effectiveness of the SDSS quasar colour–selection algorithm (Richards et al. 2002; Figures 10 & 15). If the presence of BAL troughs moves quasars further (closer) from the stellar locus in colour–space then the apparent BALQSO fraction will rise (fall). Detailed simulations to quantify the effectiveness of the final quasar–selection algorithm as a function of redshift and quasar SED will no doubt be undertaken as part of the SDSS. We conclude that there is no strong evidence favouring a significant change in the fraction of BALQSOs over the redshift range $1.5 \lesssim z \lesssim 3.5$ but that forthcoming investigations utilising the quasar catalogue from the SDSS will resolve the issue.

5.3. The BALQSO Fraction in the SDSS EDR and FBQS

The inferred incidence of BALQSOs from the LBQS, $22 \pm 4\%$, is somewhat higher than the average value of $15 \pm 1\%$ from Tolea et al. Given the smaller number of objects in the LBQS sample and the unquantified selection effects in the SDSS EDR sample, a figure of $\simeq 20\%$ for the intrinsic fraction of BAL quasars in a flux limited sample at a restframe wavelength of ~ 2100Å over the redshift range $z \sim 1.5 - 3.5$ is consistent with both surveys. The doubling of the inferred fraction of BALQSOs also reduces the apparent significance of the anomalously high fraction (7 out of 20 quasars) of BALQSOs among gravitational lenses to which Chartas (2000) draws attention.

The calculation of the intrinsic fraction of BALQSOs in both investigations is predicated on the restframe wavelengths used to define the flux–limited samples of non–BALQSO and BALQSOs. In the case of the LBQS investigation this restframe wavelength is $\simeq 2100$Å. For the Tolea et al. investigation the wavelength is very similar, ~ 2000Å (from the effective wavelength of the SDSS i–band and the typical redshift of the Tolea et al. quasars). If, in fact the SEDs of BALQSOs are redder than their non–BAL counterparts longward of ~ 2100Å then the intrinsic fraction of BALQSOs increases. It should be stressed that the two–dimensional k–correction employed in §3.2 incorporates any differences in the SEDs of non–BALQSO and BALQSOs shortward of ~ 2100Å but that it is extremely unlikely that even the continuum SEDs are identical at longer wavelengths. Sprayberry & Foltz (1992) and Yamamoto & Vansevičius (1999) both find that the differences between the SEDs of luminous non–BALQSO and BALQSOs selected in optical surveys can be explained by the presence of relatively small amounts of reddening by dust with properties similar to that in the Milky Way and the Magellanic Clouds. If such modest levels of reddening are representative of the BALQSO population as a whole then the differences in SEDs at longer wavelengths are relatively small. On the other hand, there are individual examples of reddened non–BALQSO and BALQSOs in the SDSS (e.g. Gregg et al. 2002; Hall et al. 2002) and even in the LBQS (B0059–2735; see §5.4). Compared to the LBQS, the SDSS, with its object selection, based on the i–band, at slightly longer restframe wavelength, combined with increased depth (the $i \leq 19.1$ limit reaches ~ 0.5 mag fainter down the luminosity function for typical quasars with redshifts $z \simeq 2-3$) is more sensitive to quasars experiencing small amounts of reddening. However, both the LBQS and SDSS are largely insensitive to quasars with even moderate amounts of reddening. For example, the presence of dust producing an $E(B-V)$ of only 0.25 mag, acting as a screen close to the quasar, results in a bright, $i = 17.0$, redshift $z = 2.5$, quasar falling below the SDSS i–band flux limit. Quantifying the space density of objects suffering even modest amounts of reddening will likely require a wide–field quasar sample defined at near–infrared wavelengths.

One can ask whether the numbers of BALQSOs found in the LBQS, that are also detected in the FIRST survey, are consistent with the proportion of BALQSOs found in the FBQS. Table 4 provides summary information for the 5 LBQS BAL quasars with counterparts in the FIRST catalogue. Column 1 is the LBQS name; column 2, redshift; column 3, B_J magnitude; column 4, probability the object is a BALQSO; column 5, separation, in arcseconds, between the optical position and the FIRST radio source; column 6, the integrated flux taken from the FIRST catalogue. The information in columns 1–4 is identical to the corresponding entries in Table 1.

Hewett et al. (2001) showed that the fraction of LBQS quasars included in the FIRST catalogue is 12%. Of the 42 candidate BAL quasars, with

$1.5 \leq z \leq 3.0$, 28 lie within the boundaries of the currently available FIRST survey. If the probability an LBQS quasar is detected as a FIRST source is independent of the BAL properties then the expected number of BALQSOs detected as FIRST sources is 3.4. From the comparison presented in §3.2 the probability a BALQSO is also a FIRST source is somewhat under half that for a non–BALQSO, leading to a predicted number of BALQSOs detected as FIRST sources of $\lesssim 2$. In fact, one quasar, the low–ionization object B1331–0108 (Table 4), is detected in the FIRST survey. The numbers are extremely small, illustrating the difficulty of establishing the distribution of radio–properties of BALQSOs, even with quite substantial sample sizes, but are consistent with the conclusions of §3.2, that BALQSOs are approximately half as likely to be detected as FIRST sources compared to their non–BALQSO counterparts.

Small numbers also limit what can be concluded from Tolea et al.'s analysis of their SDSS sample but their relative fraction, $5/116 \simeq 5\%$, of BALQSOs detected as FIRST sources is in good agreement with our results. In their discussion of the SDSS BALQSOs that are also FIRST sources, Menou et al. (2001) have already pointed out that the observed fraction of radio–detected BALQSOs is inconsistent with the claim of Becker et al. (2000) that BALQSOs are more common in the FBQS than in optically–selected samples. Our results, together with those of Tolea et al., based on samples defined using the BALnicity criterion, strengthen this conclusion, producing a consistent picture in which BALQSOs are approximately half as likely as non–BALQSOs to possess detections in FIRST.

A further important consistency check, to verify that the relation between the BALQSOs with $z > 1.5$ in the LBQS and FBQS is well understood, would be to verify that the SEDs of the BALQSOs in the FBQS are not significantly different from the optically–selected objects used to derive the two–dimensional k–correction of §3.2. Unfortunately, the relatively long wavelength ($\simeq 4000$Å) of the blue edge of the FBQS spectra, combined with the low redshift of many of the $z > 1.5$ BALQSOs means there is insufficient restframe wavelength coverage to perform a useful comparison.

5.4. LoBALs and FeLoBALs

Following the identification of the prototype object, B0059–2735 (Hazard et al. 1987), a key finding of the FBQS survey (Becker et al. 1997) and more recently of the SDSS survey (Hall et al. 2002) has been the definition of a subset of the low–ionization BALQSOs ("LoBALs") that show strong and complex absorption from low–ionization species including excited states of Fe+. Extreme examples of these objects, often referred to as FeLoBALs are given by Hall et al. (2002). Notwithstanding the inclusion of the prototype FeLoBAL, B0059-2735, in the LBQS, optical surveys with relatively bright flux–limits at blue wavelengths are largely insensitive to the detection of such objects because of their very large BAL k–corrections in blue passbands.

Given the tiny number of objects, analysis of the statistics of BALQSOs in the redshift interval, $0.3 \leq z \leq 1.0$, where Mg II λ2798Å broad absorption is detectable, has been confined to the calculation of the observed fraction in the LBQS (§3.1). There is little more quantitative that can be said, although, of the 4 LBQS candidate BALQSOs with $0.3 \leq z \leq 1.0$ within the FIRST survey boundaries, 2 are detected as FIRST sources, B1016–0248 and B1235+1807B (Table 4). Extending the redshift range, to include all 25 LBQS candidate BALQSOs not in the redshift range $1.5 \leq z \leq 3.0$, produces 4 detections out of the 21 objects within the FIRST survey boundaries. The 4 quasars are B1016–0248, B1235+1807B, B0059—0205 and B1138–0126 (Table 4). The quasar B1138–0126, also a low–ionization BALQSO, is in fact a Fanaroff–Riley class II, radio–loud source, that has been discussed by Brotherton et al. (2002). Thus, 4 of 21 objects are detected in FIRST and the 3 objects with reliable ionization classifications are all low–ionization BALQSOs. The statistics suggest that there may be an affinity between the presence of low–ionization BALQSOs and radio emission at intermediate radio power. However, much larger samples are required to establish such a relationship.

5.5. A Radio/BALQSO Dichotomy?

One very important result of the FBQS has been to question and indeed break the apparent dichotomy between the presence of BAL troughs and strong radio emission. In this paper the phrase "FIRST detection" has been used instead of "radio loud" since the former does not necessarily imply the latter. Clearly, samples of objects satisfying any classical definition of "radio loud" do contain unambiguous examples of BALQSOs (e.g., Gregg et al. 2000; Brotherton et al 2002). However, the statistics of samples defined according to positive values of BALnicity in the redshift range $1.5 \lesssim z \lesssim 3.5$ show that the frequency of BALQSOs with $S_{1.4\mathrm{GHz}} \gtrsim 1\,\mathrm{mJy}$ is approximately half that for non–BALQSOs. This conclusion is consistent with previous studies of the incidence of BALQSOs detectable at radio wavelengths (e.g., Brotherton et al. 1998), given the very small number of detections involved.

As noted above, the issue of the "radio avoidance" of BALQSOs is not a simple binary question, i.e., it is clear that some bona fide BAL quasars are radio loud. Furthermore, evidence is also mounting that the "associated absorbers" often seen in the rest ultraviolet spectra of radio loud quasars may be signaling the presence of outflows that are related to those of BAL flows (see papers in Crenshaw et al. 2002). As noted by Weymann (2002), it is no longer profitable to argue over whether a specific absorption system is truly a BAL trough or whether a specific BALQSO is radio loud. Instead, efforts should be concentrated on understanding the connection between radio power and the character of the outflows. One strategy for this line of research would be to examine the ultraviolet absorption properties of very powerful radio quasars. To that end, we are currently analyzing a moderately large sample of extremely radio loud quasars in hopes of shedding some light on this issue (Weymann et al., in preparation).

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AAS LaTeX macros v5.0.

Table 1

LBQS Broad Absorption Line Quasars

LBQS Name	R.A. (J2000.0)	Dec. (J2000.0)	z	B_J	Probability P(BAL)	BALnicity ($\mathrm{km\,s^{-1}}$)	Class	Reference
B0004+0147	00 07 22.50	+02 04 12.5	1.710	18.13	1.0	255	···	K
B0009+0219	00 12 19.67	+02 36 35.7	2.642	17.99	1.0	1738	···	···
B0018+0047	00 21 27.91	+01 04 19.9	1.835	17.82	1.0	329	···	K
B0019+0107	00 22 27.48	+01 24 12.7	2.130	18.09	1.0	2305	H	K,W
B0020-0154	00 23 02.34	−01 38 16.2	1.460	18.27	1.0	1502	···	···
B0021-0213	00 24 10.90	−01 56 47.1	2.348	18.68	1.0	5179	H	K,W
B0022+0150	00 24 35.35	+02 06 48.3	2.826	18.35	1.0	224	···	K
B0025-0151	00 27 33.80	−01 34 52.3	2.076	18.06	1.0	2878	H	K,W
B0029+0017	00 31 35.58	+00 34 21.1	2.253	18.64	1.0	5263	H	K,W
B0045-2606	00 48 12.56	−25 50 04.2	1.242	18.05	0.7	292	···	···
B0049-0123	00 51 35.29	−01 07 09.4	1.560	17.84	0.7	28	···	···
B0049-2535	00 52 11.07	−25 18 58.3	1.528	18.52	0.3	1936	···	···
B0051-0019	00 53 55.14	−00 03 09.4	1.713	18.67	1.0	3244	···	K
B0054+0200	00 56 44.65	+02 16 30.1	1.872	18.65	1.0	498	···	K
B0059-0206	01 02 05.60	−01 50 38.5	1.321	18.76	1.0	···	···	···
B0059-2735	01 02 17.04	−27 19 50.0	1.593	18.13	1.0	11053	L	K,W
B0103-2753	01 05 34.75	−27 36 58.2	0.848	18.07	1.0	···	L	···
B0106-0113	01 08 55.03	−00 57 47.1	1.668	18.07	1.0	377	···	···
B0109-0128	01 12 27.59	−01 12 21.8	1.758	18.32	1.0	399	···	···
B1009+0222	10 11 49.00	+02 07 31.8	1.349	18.62	1.0	1565	···	K
B1016-0248	10 19 00.86	−03 03 50.3	0.717	18.46	0.3	···	L	···
B1029-0125	10 31 49.51	−01 41 11.1	2.029	18.68	1.0	1848	H	K,W
B1133+0214	11 36 31.88	+01 58 00.6	1.468	18.38	1.0	1950	···	···
B1136-0109	11 39 04.42	−01 26 24.8	1.378	18.48	0.3	189	···	···
B1138-0126	11 41 11.62	−01 43 06.6	1.266	18.52	1.0	3523	L	···
B1203+1530	12 06 26.14	+15 13 35.4	1.628	18.70	1.0	1517	···	···
B1203+1703	12 06 20.17	+16 46 39.1	1.401	18.71	0.7	1052	···	···
B1205+1436	12 08 25.34	+14 19 20.9	1.643	18.38	1.0	788	H	K,W
B1208+1535	12 11 25.46	+15 18 51.5	1.961	17.93	1.0	4545	H	K,W
B1212+1445	12 14 40.28	+14 28 59.5	1.627	17.87	1.0	3618	H	K,W
B1214+1753	12 16 56.88	+17 37 13.3	0.679	17.65	0.7	···	L	···
B1216+1103	12 19 30.93	+10 47 00.9	1.620	18.28	1.0	4791	H	K,W
B1219+1244	12 22 21.75	+12 28 20.0	1.309	18.66	1.0	3138	···	···
B1224+1349	12 26 35.58	+13 32 51.6	1.838	18.18	1.0	420	···	···
B1228+1216	12 31 16.43	+12 00 24.1	1.408	17.54	1.0	496	···	K
B1230+1705	12 33 10.69	+16 49 05.8	1.420	18.44	1.0	2945	···	···
B1231+1320	12 33 55.62	+13 04 08.9	2.380	16.86	1.0	3473	L(0.67)	K,W
B1234+0122	12 37 24.55	+01 06 15.2	2.025	18.00	1.0	4	H	W
B1235+0216	12 38 13.01	+02 00 19.6	0.672	17.65	0.7	···	L	···
B1235+0857	12 37 54.82	+08 41 06.4	2.898	18.17	1.0	815	H	K,W
B1235+1453	12 37 36.40	+14 36 40.5	2.699	18.56	1.0	2657	H	K,W

Table 1—*Continued*

LBQS Name	R.A. (J2000.0)	Dec. (J2000.0)	z	B_J	Probability P(BAL)	BALnicity ($\mathrm{km\,s^{-1}}$)	Class	Reference
B1235+1807B	12 38 20.22	+17 50 38.0	0.449	16.86	1.0	···	L	···
B1236+0128	12 39 11.52	+01 12 13.6	1.262	17.64	0.3	···	···	···
B1239+0028	12 42 02.65	+00 12 28.8	1.214	17.46	1.0	1733	···	···
B1239+0955	12 41 35.89	+09 39 31.5	2.013	18.38	1.0	708	···	K
B1239-0231	12 41 57.33	−02 47 32.1	1.234	17.72	0.3	···	···	···
B1240+1607	12 43 03.62	+15 50 47.6	2.360	18.84	1.0	2867	H	K,W
B1243+0121	12 45 51.45	+01 05 05.0	2.796	18.50	1.0	5953	H	K,W
B1314+0116	13 17 14.23	+01 00 13.0	2.686	18.65	1.0	2626	H	K,W
B1326-0249	13 28 50.00	−03 04 50.4	1.407	18.74	0.3	···	···	···
B1331-0108	13 34 28.05	−01 23 48.8	1.881	17.87	1.0	7911	L	K,W
B1429-0036	14 31 43.77	−00 50 11.9	1.180	17.76	1.0	1500	···	···
B1442-0011	14 45 14.84	−00 23 58.4	2.226	18.24	1.0	5142	H	K,W
B1443+0141	14 45 45.29	+01 29 12.4	2.451	18.20	1.0	7967	H	K,W
B2111-4335	21 15 06.97	−43 23 09.5	1.708	16.68	1.0	7249	···	···
B2116-4439	21 20 11.66	−44 26 53.8	1.480	17.68	1.0	2594	···	···
B2140-4552	21 43 28.91	−45 38 50.7	1.688	18.30	1.0	1410	···	···
B2154-2005	21 57 05.92	−19 51 13.6	2.035	18.12	1.0	962	H	K,W
B2201-1834	22 04 01.61	−18 19 42.0	1.814	17.81	1.0	1612	H	K,W
B2208-1720	22 11 15.47	−17 05 25.4	1.210	17.65	1.0	4271	···	···
B2210-1751	22 13 09.65	−17 37 01.5	1.557	17.86	0.3	···	···	···
B2211-1915	22 14 37.90	−19 00 57.3	1.952	18.02	1.0	27	···	W
B2212-1759	22 15 31.68	−17 44 08.7	2.217	17.94	1.0	2221	···	K
B2239+0007	22 41 47.34	+00 22 54.4	1.440	18.28	0.3	···	···	···
B2241+0016	22 44 31.49	+00 32 25.8	1.394	18.30	1.0	396	···	···
B2350-0045A	23 52 53.50	−00 28 50.7	1.617	18.63	1.0	6964	L(0.27)	K,W
B2358+0216	00 01 21.70	+02 33 04.9	1.872	18.61	1.0	6283	···	K

Table 2
Observed and Intrinsic Fractions of Broad Absorption Line Quasars in the LBQS

Redshift Interval	Magnitude Interval	n_{total}	$\sum$ non–BAL	n_{BAL}	$\sum$ BAL	Fraction
			A. Observed Fractions			
1.5 - 3.0	16.50 - 18.85	375	537.9	40.3	97.1	0.15±0.03
1.3 - 3.0	16.50 - 18.85	475	687.5	50.9	112.0	0.14±0.03
1.5 - 3.0	16.50 - 18.41	221	209.8	28.0	30.4	0.13±0.03
1.3 - 3.0	16.50 - 18.41	281	268.1	34.3	37.3	0.12±0.03
1.5 - 3.0	18.42 - 18.85	154	328.1	12.3	66.4	0.17±0.04
1.3 - 3.0	18.42 - 18.85	194	419.4	16.6	74.8	0.15±0.04
0.3 - 1.0	16.50 - 18.85	379	643.2	3.6	5.8	0.01
			B. Intrinsic Fractions			
1.5 - 3.0	16.50 - 18.85	375	537.9	40.3	152.8	0.22±0.04
1.5 - 3.0	16.50 - 18.41	221	209.8	28.0	46.2	0.18±0.03
1.5 - 3.0	18.42 - 18.85	154	328.1	12.3	106.6	0.24±0.04

Table 3
Composite Spectra from the WMFH Quasar Sample

Name	n_{quasar}	BALnicity Interval ($\mathrm{km\,s^{-1}}$)	Mean BALnicity ($\mathrm{km\,s^{-1}}$)
Com_non–BAL	29	0	0
Com_BAL_1	9	1501-3000	2337
Com_BAL_2	15	3001-6000	5093
Com_BAL_3	11	≥6001	8669
Com_BAL_3_H	6.5	≥6001	7990
Com_BAL_3_L	4.5	≥6001	9689

Table 4
LBQS BALQSO Candidates with FIRST Detections

LBQS Name	z	B_J	P(BAL)	Separation (arcsec)	$S_{1.4\mathrm{GHz}}$ (mJy)
B0059–0205	1.321	18.76	1.0	0.4	1.81 ± 0.15
B1016–0248	0.717	18.46	0.3	0.2	3.29 ± 0.16
B1138–0216	1.266	18.52	1.0	8.1[a]	252 ± 0.5
B1235+1807B	0.449	16.86	1.0	1.0	6.07 ± 0.14
B1331–0108	1.881	17.87	1.0	0.3	2.99 ± 0.14

[a]Distance to closest of the two associated radio–lobes.

FIGURE CAPTIONS

Fig. 1.— BAL k–correction, in magnitudes, as a function of redshift. The individual data points were derived from the difference in B_J magnitude for each of the 5 composite BALQSO spectra, listed in Table 3, compared to the composite non–BALQSO spectrum. The individual data points have been joined to guide the eye. The locus corresponding to a particular composite spectrum can be identified using the values of the mean BALnicity given in column 4 of Table 3.

Fig. 2.— Graphical illustration of the procedure used to calculate the fraction of BALQSOs in the sample after correcting for the k–correction due to the difference in SEDs shortward of 2100Å. The distribution of quasars (•) within specified redshift and magnitude limits (dashed rectangle) is shown. The open symbol denotes a BALQSO, the k–corrected magnitude of which is indicated by the top of the upper arrow. The dot–dash line shows the k–corrected magnitude for the quasar at all redshifts. The corrected limiting magnitude for non–BALQSOs (solid line) that corresponds to the detection of the BALQSO at the faint limit of the sample also moves brightward by the same amount (lower arrow). The ratio of the total number of non–BALQSOs to the number of non–BALQSOs within the shaded region determines the weighting applied to the BALQSO.